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Validation of a computerized scoring system for foreign body aspiration: An observational study

Patrick Stafler MD[1,2] | Yuval Nachalon MD[3] | Yoram Stern MD[2,3] | Moshe Leshno MD, PhD[2] | Meir Mei Zahav MD[1,2] | Dario Prais MD[1,2] | Gili Kadmon MD[2,4]

[1]Pulmonary Institute, Schneider Children's Medical Center of Israel, Petah Tikva, Israel

[2]Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

[3]Ear, Nose, and Throat Clinic, Schneider Children's Medical Center of Israel, Petah Tikva, Israel

[4]Pediatric Intensive Care Unit, Schneider Children's Medical Center of Israel, Petah Tikva, Israel

Correspondence
Patrick Stafler, MD, Schneider Children's Medical Center in Israel, 14 Kaplan St, 4920235 Petah Tikva, Israel.
Email: pstafler@hotmail.com

Abstract

Objective: The diagnosis of foreign body aspiration (FBA) is challenging. In a previous study, we developed a computerized scoring system (CSS) to support decision-making. In the present study, we aimed to validate it on a further cohort.

Study Design: In this observational study, 100 children referred to the emergency department of a tertiary pediatric hospital for suspected FBA and treated according to standard protocol, were assigned a probability score using the CSS, between 0 and 1 (0, very low probability; 1, very high). The diagnosis of FBA was based on bronchoscopy, and if discharged without bronchoscopy, determined via telephone questionnaire, 4 to 6 months after discharge, supplemented by clinical re-evaluation and bronchoscopy, if respiratory symptoms persisted.

Results: Thirty-five out of 100 children (35%) underwent bronchoscopy with 12 of 35 (34%) positive for FBA. Sixty-five patients were discharged without bronchoscopy and completed a telephone questionnaire. Seven patients required clinical re-evaluation for persistent respiratory symptoms, in two out of them, additional bronchoscopies were performed and were negative. The CSS median probability score was 0.94 in patients with FBA, as compared to 0.73 in patients without FBA ($P = .007$). The CSS area under the receiver operating curve was 0.74. At a probability score threshold of 0.6, the sensitivity and specificity were 100% and 41%, respectively.

Conclusion: The present validation study suggests a high sensitivity of the CSS for the identification of FBA in children. We suggest that it might aid decision-making with regard to the need for bronchoscopy in children presenting to the emergency room.

KEYWORDS

algorithm, bronchoscopy, computer, diagnosis, risk assessment

1 | INTRODUCTION

Foreign body aspiration (FBA) is one of the major causes of death in children.[1,2] Its diagnosis is challenging and if missed, significant morbidity, including recurrent pneumonia and bronchiectasis,[3,4] can result.

The gold standard for FBA diagnosis is bronchoscopy. However, this is an invasive examination requiring anesthesia and the availability of skilled pediatric pulmonologists or otorhinolaryngologists. Moreover, it carries risks, including respiratory depression secondary to anesthetic agents and airway injury.[5,6] The decision to

Abbreviations: CSS, computerized scoring system; FBA, foreign body aspiration; ROC, receiver operating characteristics.

perform bronchoscopy in cases of suspected FBA is traditionally based on a witnessed choking event, as well as clinical and radiological findings suggestive of airway obstruction. However, history is often vague and physical signs, as well as radiology findings, often subtle. In addition, neither of these findings is sufficiently sensitive or specific in their own right to reliably predict the presence of a foreign body in the airways.[7-11] Several algorithms have been proposed to aid the diagnosis of FBA in children,[11-14] combining varying constellations of parameters from history, physical examination, and radiographic findings. To the best of our knowledge, none of them have been validated in a further cohort of children with suspected FBA. As a result of this uncertainty, there is currently no consensus regarding the indications for bronchoscopy in children with suspected FBA and bronchoscopy rates vary widely.[11]

In a previous study, we developed a computerized scoring system (CSS) for the diagnosis of FBA, based on 150 children with suspected FBA who underwent bronchoscopy (Table 1).[15] A total of 21 parameters were collected from the patients' files, analyzed using multivariable logistical regression and assigned correlation coefficients for the final diagnosis of FBA. On the basis of these correlation coefficients, a downloadable CSS excel file was developed, to facilitate calculation of individual FBA probability score, ranging between 0 and 1, with 0 designating a very low and 1, a very high probability. A probability score of 0.3 was chosen as the threshold for performing flexible bronchoscopy, resulting in sensitivity and specificity of 95% and 70%, respectively. The excel sheet takes less than 1 minute to fill in by the bedside.

We proposed that this tool may serve the clinician as a decision-making aid, pending further validation. In the current study, we aimed to perform this validation by applying the CSS to a new cohort of children presenting with suspected FBA.

2 | METHODS

This was an observational study of pediatric patients with suspected FBA, who were referred to the emergency department at Schneider

TABLE 1 Excel calculator for probability assessment of foreign body aspiration

	Value	Coefficient	Parameter
0-no, 1-yes	0	0.529	Age, 10-24 mo
0-female,1-male	0	0.136	Male
0-no, 1-yes	0	–0.426	Fever prior to choking event
0-no, 1-yes	0	–2.39	Respiratory complaints prior to choking (except rhinorrhea)
0-no, 1-yes	0	0.143	Foreign body observed in mouth during choking episode
0-no, 1-yes	0	–1.216	Foreign body observed near child during choking episode
0-no, 1-yes	0	0.142	"Mild" respiratory symptoms during choking episode (cough, erythema, dyspnea, and vomiting)
0-no, 1-yes	0	0.469	"Severe" respiratory symptoms during choking episode (cyanosis, apnea, and unconsciousness)
0-no, 1-yes	0	–0.728	Fever after choking episode
0-no, 1-yes	0	–0.229	Persistent respiratory complaints in emergency room
0-no, 1-yes	0	0.162	Previous respiratory illness
0-no, 1-yes	0	0.842	Hypoxemia in emergency room
0-no, 1-yes	0	0.45	Dyspnea in emergency room
0-no, 1-yes	0	1.695	Stridor in emergency room
0-no, 1-yes	0	0.732	Bilateral findings—auscultation
0-no, 1-yes	0	1.588	Unilateral findings—auscultation
0-no, 1-yes	0	0.879	Unilateral findings—chest radiography
0-no, 1-yes	0	–1.449	Bilateral findings—chest radiography
0-no, 1-yes	0	1.206	Local hyperinflation on chest radiograph
0-no, 1-yes	0	1.632	Obstructive emphysema on chest radiograph
0-no, 1-yes	0	0.674	Tracheal radiography suspicious for FBA
	Score		
	0		
			FBA probability (0- minimum/ very low risk; 1- maximum/ very high risk)
	0.5		

Children's Medical Center of Israel, a tertiary, University-affiliated, pediatric hospital, between March 2014 and June 2016. The study was approved by the local Institutional Review Board (0116-13-RMC) and the need for informed consent was waived, due to the observational design of the study.

2.1 | Clinical protocol

At our institution, any child attending the emergency department with suspected FBA is presented to a board accredited pediatric pulmonologist. The child's history, physical examination, and chest radiograph findings are evaluated and a decision taken with regard to the need to proceed with a diagnostic bronchoscopy. Children deemed at low risk are discharged and followed-up clinically; those at medium risk undergo flexible bronchoscopy by a pulmonologist, when possible in tandem with rigid bronchoscopy by an otolaryngologist; and those at high risk, undergo urgent rigid bronchoscopy when possible, assisted by flexible bronchoscopy.

2.2 | Note review process

An ENT resident (YN) collected data of each child after the event and scored the parameters of the CSS to determine the risk for FBA. The attending pediatric pulmonologist evaluating the child in the emergency room took a clinical decision with regard to the need for bronchoscopy before and without knowledge of the CSS score.

Bronchoscopy results were documented. When a child was discharged without bronchoscopy, the patient's guardians were contacted by a pediatric pulmonologist (PS) 4 to 6 months after discharge and requested to complete a telephone questionnaire. This consisted of items evaluating the presence or absence of persistent breathing problems, cough, shortness of breath, respiratory noise, as well as any events of turning red or blue, chest infection requiring antibiotic treatment and visits to the emergency room or a different hospital for respiratory complaints since discharge. If any of the above answers were positive during the telephone interview, the patient was referred for re-evaluation in the pulmonology clinic and the need for bronchoscopy reconsidered. For each child, a final dichotomous diagnosis with regard to FBA was determined. For this purpose, children discharged without bronchoscopy and asymptomatic or minimally symptomatic 4 months or more post-event were considered free of FBA.

2.3 | Statistical analysis

A sample size of 100 patients was chosen, assuming 30% of the patients would be positive for FBA. The prevalence of the different parameters in patients with and without FBA was compared using the χ^2 test. A two-tailed Mann-Whitney *U* test was used to compare the probability scores of patients with and without FBA. $P < .05$ was considered statistically significant.

The sensitivity and specificity of the CSS in diagnosing FBA was calculated, as compared to the final diagnosis for each child. Positive and negative predictive values were not calculated due to the low number of actually observed FBA episodes. The receiver operating characteristic (ROC) curve of the CSS was plotted and the area under the curve calculated.

3 | RESULTS

One hundred children were included. The median age was 1.5 years (range, 0-17), 54% were male.

Thirty-five (35%) children underwent flexible bronchoscopy (Figure 1) with a foreign body observed in 12 of 35 (34%). In eight cases, the foreign body was organic, in four cases nonorganic material (eg, plastic). In five cases, the foreign body was extracted using a flexible bronchoscope exclusively. Seven patients underwent a combination of rigid and flexible bronchoscopy to extract the foreign body. No complications were noted.

Sixty-five patients were discharged without bronchoscopy and all were successfully followed up with a telephone questionnaire a median of 5 months after discharge (range, 4-17 months, 17 months being an outlier due to difficulties locating the parents). The guardians of 16 patients reported any respiratory complaints. Out of those, nine had occasional mild cough with no other respiratory complaints and seven persistent respiratory symptoms, which triggered a referral to the pulmonology clinic for clinical evaluation. Out of the seven patients with persistent symptoms, the possibility of a missed foreign body was entertained in two patients, but the ensuing bronchoscopy was normal in both. In the other five cases, physical examination and chest radiograph were normal and the clinical suspicion for missed FBA deemed very low. Therefore, the overall FBA rate remained unchanged at 12%.

The epidemiological, clinical and radiographic characteristics of the patients with and without FBA are presented in Table 2. The following parameters were significantly more prevalent in patients with FBA, as compared to patients without FBA: Male sex; foreign body observed near the child during choking episode; dyspnea in the emergency room; unilateral findings on auscultation; and chest radiographies indicative of unilateral changes, localized hyperinflation and obstructive emphysema ($P < .05$ for all).

Considering the entire sample of 100 children, the median (IQR, range) probability score for FBA as calculated by the CSS was 0.73 (0.36, range 0.05-1). The median probability for the patients with FBA was 0.94 (0.33, range 0.62-1) and for the patients without FBA was 0.73 (0.41, range 0.05-0.99, $P = .007$). The median probability for the 16 patients who had persistent symptoms and were referred for clinical re-evaluation was 0.66 (0.43, range 0.22-0.83, $P = .04$). The area under the ROC curve was 0.74 (Figure 2), representing good performance of the CSS. To achieve 100% sensitivity with maximal specificity, a probability threshold of 0.6 resulted, with a specificity of 41%.

For example, a 16-month-old boy with a witnessed choking event, consisting of cough and cyanosis ("severe" respiratory signs) while playing with peanuts, bilateral wheezing on physical examination and atelectasis of the right lower lobe, was evaluated by the pediatric pulmonologist. A decision to perform bronchoscopy was made and a foreign body was observed and extracted.

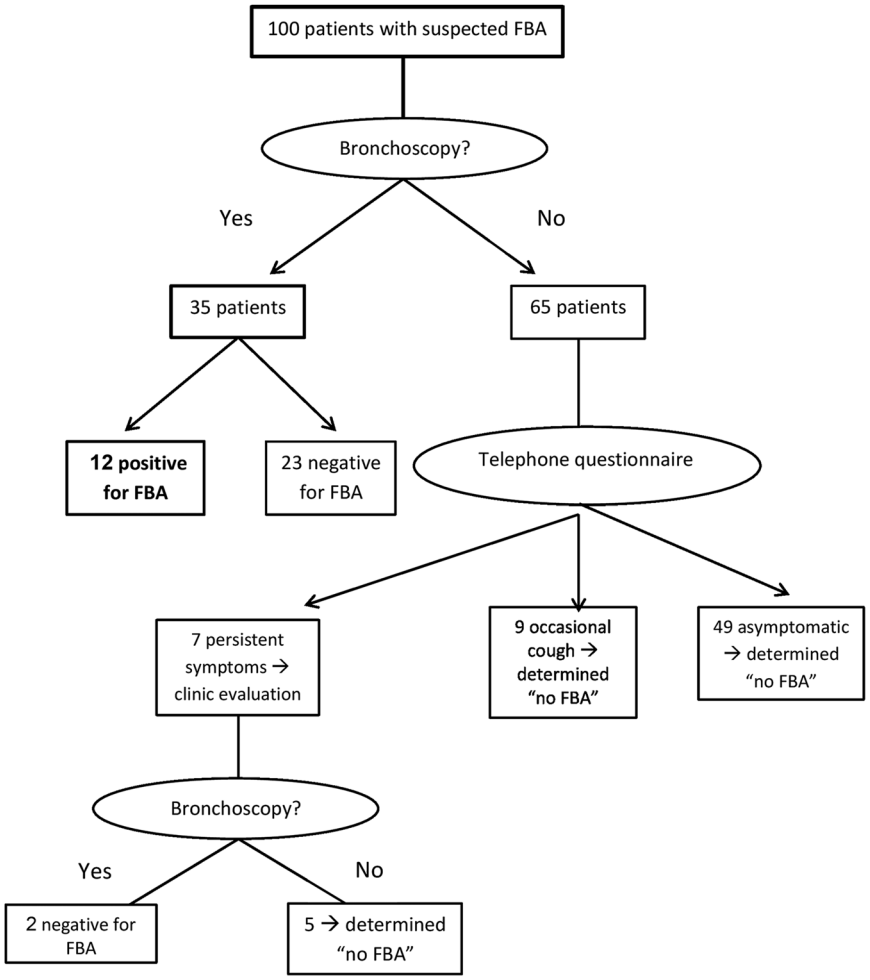


FIGURE 1 Patient flow diagram. FBA, foreign body aspiration

According to the CSS, this case received a probability score of 0.88, suggesting a need for bronchoscopy due to high FBA probability.

4 | DISCUSSION

In the present study, we validate a computerized algorithm for the diagnosis of FBA, previously developed based on a retrospective cohort of children with suspected FBA, by applying it to a cohort of 100 new cases.

4.1 | Challenges for prediction algorithms in suspected foreign body aspiration

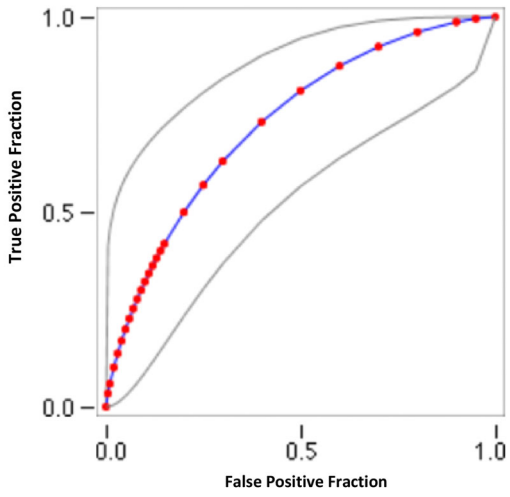
Several diagnostic algorithms have been suggested, to help clinicians with the conundrum of when to perform diagnostic bronchoscopy in suspected FBA.[11-14] While it is a noble goal to avoid unnecessary bronchoscopies, false-negative scores might sway the doubting clinician to withhold a bronchoscopy and thus miss a foreign body. It is, therefore, mandatory for any scoring system to, first and foremost, minimize misleadingly reassuring false negative scores. Where to set the bar for false-positive scores, that is, how many bronchoscopies with no foreign body found are justified, is a matter of judgment, in the context of clinical, but also cultural, philosophical, and medicolegal considerations. In some centers, this latter concern, combined with the low-risk perception of the procedure, has led to a protocol that demands a flexible bronchoscopy in each and every child with any degree of FBA suspicion. This approach was adopted by Cohen et al,[12] who studied 142 children consecutively referred to the ER for suspected FBA.[14] All automatically underwent bronchoscopy, with a 43% detection rate. The aim of their study was not to develop a risk score, but they did note that children who continued to be symptomatic (eg, cough, fever, dyspnea, and dysphagia) with no physical exam or radiologic abnormalities could still harbor a foreign body. The only group that could be safely observed, as no foreign body was found on bronchoscopy, were asymptomatic children with normal physical exam and radiologic findings.

In our cohort, according to clinical judgment, only 35 out of 100 (35%) children underwent flexible bronchoscopy, with a foreign body observed in 12 of those 35 (34%). A similar detection rate was described in a retrospective Austrian study. Their protocol stipulated bronchoscopy in cases with a combination of anamnestic observed foreign body in the mouth and either abnormal physical examination (wheezing, cough, dyspnea, or severe respiratory distress) or abnormal radiography (unilateral emphysema or opaque foreign body).[13] In all other cases, patients were observed only. The application of this

TABLE 2 Epidemiologic, clinical, and radiographic variables and their prevalence in patients with and without foreign body aspiration (FBA), n = 100

Variable	All patients[a]	Positive for FBA (N = 12), n (%)	Negative for FBA (N = 88), n (%)	*P* value
Age, 10-24, mo	52	6 (50)	46 (52)	.88
Male sex	54	10 (83)	44 (50)	**.03**
Fever before choking event	5	1 (8)	4 (5)	.57
Respiratory complaints before choking (except rhinorrhea)	18	2 (17)	16 (18)	.9
Foreign body observed in mouth during choking episode	70	9 (75)	61 (69)	.69
Foreign body observed near child during choking episode	14	5 (42)	9 (10)	**.003**
Mild respiratory symptoms during choking episode (cough, erythema, dyspnea, and vomiting)	73	9 (75)	64 (73)	.87
Severe respiratory symptoms during choking episode (cyanosis, apnea, and unconsciousness)	19	3 (25)	16 (18)	.57
Fever after choking episode	20	2 (17)	18 (20)	.76
Persistent respiratory complaints in emergency room	65	9 (75)	56 (64)	.44
Previous respiratory illness	13	2 (17)	11 (13)	.69
Hypoxemia in emergency room	4	0 (0)	4 (5)	.45
Dyspnea in emergency room	24	6 (50)	18 (20)	**.02**
Stridor in emergency room	6	1 (8)	5 (6)	.72
Bilateral findings—auscultation	17	2 (17)	15 (17)	.97
Unilateral findings—auscultation	28	8 (67)	20 (23)	**.001**
Unilateral findings—chest radiography	20	6 (50)	14 (16)	**.006**
Bilateral findings—chest radiography	30	3 (25)	27 (31)	.69
Local hyperinflation on chest radiograph	8	3 (25)	5 (6)	**.02**
Obstructive emphysema on chest radiograph	1	1 (8)	0 (0)	**.007**
Tracheal radiography suspicious for FBA	0	0 (0)	0(0)	NA

Note: The significance for all *P*-values in table is $P < .05$.
[a]n = 100, therefore the rate and % are identical.



ROC – receiver operating characteristic. Area under the curve = 0.74, representing good prediction.
Red symbols and blue line: Fitted ROC curve.
Gray lines: 95% confidence interval of the fitted ROC curve

FIGURE 2 ROC (receiver operating characteristics) curve of the scoring system in the present cohort [Color figure can be viewed at wileyonlinelibrary.com]

algorithm resulted in a high bronchoscopy rate, at 63 out of 77 (82%), with a foreign body detection rate of 25 out of 63 (40%). The sensitivity and specificity were 100% and 34%, respectively, also similar to ours, but at a price of higher bronchoscopy rate.

Janahi et al[11] analyzed 300 cases of suspected FBA, all of whom were highly suspicious and underwent bronchoscopy. Similar to our approach, they used a multivariable logistic regression analysis to identify significant predictors, including choking, noisy breathing/stridor/dysphonia, wheeze, abnormal radiology, and unilaterally reduced air entry. They proposed a scoring system between 0 and 7, concluding that children with a score of 2 or more would have to proceed to bronchoscopy, with a sensitivity of 89% and specificity of 45%. Despite setting the bar quite low, the sensitivity was slightly less than in our study and the specificity only marginally higher.

Haller et al[14] also proposed a diagnostic algorithm for pediatric FBA. Comparing their 23 patients with foreign body to 47 without, symptoms and clinical signs that were statistically significantly different between the groups were cyanosis, sudden choking, apnea, and unilaterally decreased breath sounds. They found that when none of these were present, which was the case in 15 of 70 patients, no foreign body was found. They, therefore, propose avoiding

bronchoscopies when none of these criteria is met. The emphasis on history and physical examination with lack of reliance on radiographical features is in keeping with Cohen et al's[12] approach and might indeed serve to raise the specificity of scoring systems. To the best of our knowledge, none of the hitherto proposed algorithms have been validated by applying them to a further cohort of suspected pediatric FBA cases.

4.2 | Validation of our algorithm

In this present observational study, we aimed to validate our previous results, by applying our algorithm to 100 new cases, managed according to the standard protocol at our institution.

We determined an FBA probability score for each child according to the previously developed scoring system and compared it to the final outcome, obtained from bronchoscopy or telephone questionnaire and clinical re-evaluation 4 to 6 months post-event. The discriminative ability of the scoring system was good, with an area under the ROC curve of 0.74. We decided to apply a probability cutoff of 0.6, to achieve a sensitivity of 100%. Considering the choice of such a sensitive cutoff, the resulting specificity was reasonable at 41%, consistent with previously published algorithms. Had we aimed for higher specificity, this would have come at the expense of, and lowered, the sensitivity, potentially risking missed cases of FBA. Seeing that we are devising a screening tool, we regard 100% sensitivity to be of tantamount importance.

Compared to our original study, the current probability threshold for flexible bronchoscopy was higher at 0.6 compared to the prior 0.3. This means that in the current cohort, the prediction algorithm resulted in higher certainty with regard to ruling out FBA based on clinical and radiological parameters, compared to the original cohort. This is most likely grounded in the difference between the two cohorts: The original sample was exclusively composed of children who actually underwent bronchoscopy, favoring more severe cases and thereby introducing selection bias. Our current sample, including children with any suspicion of FBA, out of which only one-third went through to bronchoscopy, represents children with lower pre-test probability. It resembles the real-world scenario more closely in that front line physicians have to face the uncertainty of any child presenting with as much as a suspicion. These patients have a lower risk of FBA a priori and require a higher threshold of pre-bronchoscopy probability to warrant further workup. Even apparently simple risk indicators, such as chest radiographs, are not sufficiently sensitive for the diagnosis of FBA when regarded in isolation. This is demonstrated by the fact that for three of the five radiology-related parameters in the CSS, a majority of patients with unilateral findings did not have a final diagnosis of FBA.

It is noteworthy that in our cohort, not a single case of FBA was seemingly missed by the pediatric pulmonologists' initial emergency-room evaluation. Even after telephone with or without clinical follow-up of discharged children who had not undergone bronchoscopy, no missed FBA case was identified. By choosing a 4- to 6-months follow-up period, we presume that most foreign bodies would have manifested by the time of review. However, the presence of smaller missed foreign bodies or spontaneous expectoration cannot be entirely ruled out. As such, telephone follow-up can never be considered 100% sensitive.

The application of the proposed CSS is henceforth expected to reap the most benefit in resource poor settings, with limited out-of-hour access to subspecialists, such as pediatric pulmonologists and ENT surgeons. Although intermediate scores might not necessarily help to establish the need for bronchoscopy, a high or low score is expected to assist the busy emergency-room physician in determining the urgency of airway evaluation or referral to a tertiary center.

With the advent of low-radiation computed tomography (CT), some authors have advocated its use in the context of suspected FBA, to reduce exposure to operative and anesthetic risks and costs.[16,17] Ahmed et al[17] developed a protocol for selective use of low-dose CT for children with intermediate risk for FBA based on clinical exam and chest radiography. Airway CT was highly sensitive and specific for FBA and they were able to reduce negative bronchoscopy rates from 37% to 17%. The risks concurrent with airway instrumentation would hence be mitigated, but since the population at risk is of very young age, an anesthetic would be inevitable for even short duration CT scans. Even though the CSS carries a poorer negative predictive value than CT informed scores, its safety and immediate availability render it a useful adjunct for clinical decision-making.

Our study has several limitations. The main shortcoming is that a large proportion of children did not undergo bronchoscopy, begging the question how many foreign bodies might have been missed. However, a thorough follow-up protocol, including a telephone questionnaire applied by a pediatric pulmonologist and follow-up visits, supplemented by bronchoscopy when deemed necessary, is likely to have eliminated or, at least, significantly reduced these false-negative cases. The five (out of 100) children with persistent respiratory symptoms, but normal auscultation and chest X-rays at recall most likely reflect the expected 5% background population rate of children with hyperactive airway disease.

In addition, the specificity of the scoring system with a probability cutoff of 0.6 was low, at 41%. This means that if every case with a probability score 0.6 or greater, is referred for flexible bronchoscopy, no FBA will be missed, but 6 out of every 10 bronchoscopies will be normal. Since the CSS features as a screening tool and geared towards avoiding any false negatives, we regard sensitivity to be more important and are prepared to accept the relatively low specificity, in keeping with other algorithms.

5 | CONCLUSION

In summary, the present validation study suggests high sensitivity of the CSS for identification of FBA in children. The score, attainable via an easily applied excel sheet, can act as a valuable teaching tool and clinical guide for front line physicians in the emergency department, tasked with the decision about whom to refer for bronchoscopy.

Further studies are needed to examine the CSS in different settings, larger populations, and various ages.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ORCID

Patrick Stafler http://orcid.org/0000-0001-8880-8212
Meir Mei Zahav http://orcid.org/0000-0002-6683-0264

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